Full Stokes polarimetry based on the polarization-holographic diffraction element of an optimal configuration

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Abstract. The new polarization-holographic element of an optimal configuration is developed for the real-time complete analysis of the polarization state of light (for determining all Stokes parameters). The simultaneous measurement of the intensities in all points of images in diffracted orders using CCD camera and appropriate software allows to determine the spatial distribution of a polarization state in the images of objects, and also the dispersion of this distribution.

1 Introduction

The information capacity of the methods of determining the objects characteristics essentially increases when together with other characteristics of light reflected from an object the polarization state is taken into account. In this case the additional parameters of information processing are introduced.

Polarization-holographic method was first proposed by Prof. Sh. Kakichashvili [1,2]. It gives the possibility to create polarization-holographic elements (PHE) which enables to carry out a complete analysis of the state and degree of polarization in real time and work in a wide spectral range including infrared [3,4]. We proposed an innovative polarimetric method based on such an integral polarization-holographic element.

Currently, the existing polarimeters allow measuring linear, circular, or elliptical polarization in different areas of the light spectrum with relatively high accuracy, and spectral and spatial resolution. However, it is still impossible to optimize all these parameters simultaneously and to obtain the distribution of polarization properties in extended objects in real-time with a high cadency. This restrains the polarimetric studies of objects with space-time instability or rapid variability. Besides, the existing polarimeters have a significant instrumental polarization due to internal reflections in an optical system.

The development of a new polarimetric method based on a simple construction and user-friendly device to measure all four Stokes parameters simultaneously in real-time, which allows the temporal and spatial distribution of polarization state to be estimated on the image of object is an essential and actual task.

2 Polarization-holographic diffraction element

Besides, in polarization holography there is a possibility of recording several polarization gratings on the same area of polarization-sensitive material so that holograms will be independent of each other while the special technology of shooting is used. We use this property for obtaining the integral polarization-holographic element on which several gratings are recorded so that the beams diffracted on each grating are spatially divided.

We used earlier the configuration of the element from three polarization-holographic gratings: gratings “C” recorded by two orthogonally circularly polarized beams, gratings L_{90} recorded by two parallel linearly polarized beams with azimuth 90^{0} and grating L_{45}, recorded by two parallel linearly polarized beams with azimuth 45^{0}.

Such an element decomposes incident light into six diffraction orders. The simultaneous measurements of intensities of four diffracted orders allow the real-time complete analysis of the polarization state of light to be carried out (to determine all four Stokes parameters) through the relations developed [4]. Note that the polarization-holographic element of such configuration forms 6 diffraction orders, only four of which are used during analysis, At the same time, the intensities of two diffracted orders remain unused which significantly reduces the efficiency of the element. Such a configuration was caused by the need to use real-existing recording polarization-sensitive materials for which the functions of reaction to polarized light do not satisfy a certain condition [5].

To obtain a highly efficient polarization-holographic element, an element with an optimal configuration has been developed when only two gratings are recorded on the same area of the recording material: the "C" grating recorded with two circularly, orthogonally

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polarized beams, and the "L" grating recorded with two linearly polarized beams with azimuths of 90 and 45 degrees. Such an element forms 4 diffraction orders and also a non-diffracting beam with a state of polarization identical to the incoming beam by a state of polarization. In this case, the energy of the light wave losses on the element is minimal, the energy will be distributed between the four diffraction orders, which significantly increases the efficiency of the element. We have developed a method to compensate the distortion caused by the characteristics of the recording material.

We have obtained all the four Stokes parameters of a light source that is being analyzed through the intensities of the beams diffracted on the polarization-holographic element taking into account also the spectral dispersion of an element.

$$S_{0,\lambda_i} = k_{C,\lambda_i} I_{+C} + k_{C,\lambda_i} I_{-C}$$

$$S_{1,\lambda_i} = (k_{C,\lambda_i} I_{+C} + k_{C,\lambda_i} I_{-C}) - 2k_{90,\lambda_i} I_{90}$$

$$S_{2,\lambda_i} = 2k_{45,\lambda_i} I_{45} - (k_{C,\lambda_i} I_{+C} + k_{C,\lambda_i} I_{-C})$$

$$S_{3,\lambda_i} = k_{C,\lambda_i} I_{+C} - k_{C,\lambda_i} I_{-C}$$

Here k_{90,λ_i}, k_{45,λ_i}, k_{C,λ_i} are coefficients connected with the absorption of light in an element, the diffraction efficiency of an element, wavelength and the optoelectronic transformations by a photodetector. These coefficients are determined. The values of these coefficients are determined experimentally during the calibration of the element.

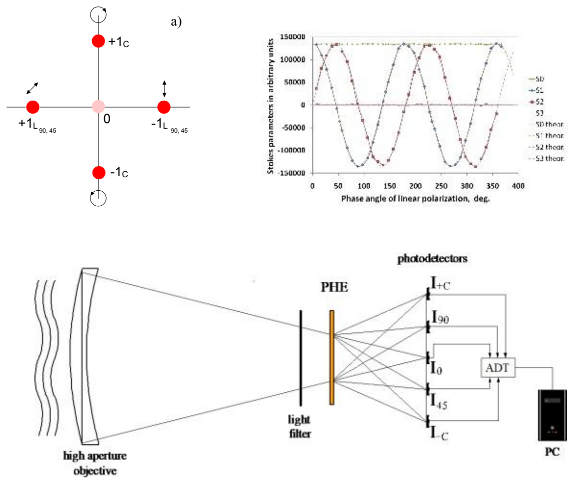
This equation shows that the intensities of 4 orders I_{+C}, I_{-C}, I_{90} and I_{45} fully and unambiguously describe all four Stokes parameters through the corresponding coefficients. Simultaneously measuring the intensities of diffracted beams by a photometric detector we can carry out a complete analysis of the polarization state of light in real time, i.e. determine all the four Stokes parameters and the corresponding parameters of the polarization ellipse at a time of observation simultaneously: ellipticity, direction of rotation, azimuth and degree of polarization. Let us note that such an element is able to work in a wide optical spectral range and have an angular dispersion which gives a possibility to determine also the spectral dispersion of the polarization state.

3 Recording material

The preliminary recording of the optical element was carried out on a medium, which is a two-component composition of organic polarization-sensitive material. As a light-absorbing component, we chose a highly effective functional bisazodye synthesized by us with four ionogenic groups in the form of a tetrasodium salt (MPY4Na-Dimer). A factory-made tanned photogelatin film was used as a polymer base of the material. An appropriate chemical process removed the available silver halide, and the remaining transparent polymer film was impregnated by immersion in a saturated aqueous solution of the chromophore component mentioned above. The photoanisotropic material obtained in this way shows a pronounced sensitivity to the linearly polarized recording beam of light we used with a wavelength of 445 nm. It should be noted that, because of the hydrophilic nature of the entire composition, the resulting optical elements based on them should be protected from atmospheric moisture immediately after drying by sealing them with a cover glass.

4 Full Stokes polarimetry

Based on such an element we have developed the optical scheme for full Stokes polarimetry to determine the polarization state of light and the distribution of a polarization on the object image for different spectral ranges [5]. A schematic picture of diffraction on the polarization-holographic element, the result of element calibration and an optical scheme of the laboratory set-up are shown sequentially on the Figure below:



5 Conclusion

The information on the polarization state of light transmitted or reflected by different objects plays an increasing role in remote sensing, ellipsometry, astropolarimetry, object recognition and others. Therefore, the development of a simple, precise and real-time full Stokes polarimetric method for determining the polarization state and the distribution of polarization state on the images of different objects, taking also into account a dispersion of this distribution is rather urgent.

References

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